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A Review of the Mechanism, Effects and Control of Ground Vibration Associated With Rock Blasting

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Abstract: *Ground vibration is one of the major devastating effects of blasting. Blasting is a term that is synonymous with mining of economic minerals, quarryingand engineering works where it is being used to construct underground tunnels (tunneling). In Nigeria, individuals, companies and cooperate bodies have commercialized mineral extraction through small scale and sometimes large scale mining activities which are usually accompanied by rock blasting. Chippings from crushed rock is a product of rock blasting commonly used for construction of engineering structures such as roads, bridges and houses. In general, the overall economic benefits of rock blasting outweigh the adverse effects, but notwithstanding, rock blasting as a practice does not only alter the serenity of a natural environment but induces ground vibration in the earth. This however causesenvironmental degradation and high level of destruction to structures on the surface. Its effects include: shock waves, crack walls and sometimes landslide. The windows, rooftops and glass doors of most buildings are usually destroyed while the residents of such communities are left to battle with noise pollution resulting from air blast. Ground vibration is widely reported as one of the major components of environmental pollution. During geophysicalexploration, a form of blasting known as seismic blasting is the fundamental method used in seismic data acquisition for hydrocarbon and mineral exploration. This, also induces vibration in the ground through the passage of seismic waves. However, if the blast planis carefully designed and blast parameters appropriately chosen, these effects can be controlled. This paper therefore, seeks to highlight the mechanism, effects and control of ground vibration associated with rock blasting.*

Keywords*: Blasting, Mechanism, effects, control, vibration, associated, rock.*

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I. INTRODUCTION

Blasting is a systematic way of reducing the size of a solid mass such as rock body into fragments of tiny particles using explosives. It involves placing and detonating explosives in drill holes in order to reduce the rock into desired fragments for the use of man (Agbeno, 2011). Blasting could either be primary or secondary depending on how it is carried out. An explosive is amixture of compounds which when ignited by heat, impact friction and undergo a sudden decomposition releasing a large amount of energy.The detonation of explosives causeselastic waves to travel in all directions from the blast point resulting in ground vibration which if in excess may cause damage to the structures within the blast vicinity (*Aket al.,*2009*;* Arpaz and Elevi 2010; Nateghi, 2011).Two forms of energy are usually released when explosives react. There are shock energy and gas energy (Anon, 2013a). The results of the energy released are rock fragmentation, rock displacement, ground vibration and air blast (Anon, 2013b). A detonator on the otherhand is device which triggers explosive. Blasting is a common practice associated with mining of solid minerals, quarrying, engineering construction works and tunneling. In geophysics, blasting is done during seismic survey and data acquisition. Blasting however, cannot be achieved without the use of explosives. These explosives come in different forms and exhibit different power characteristics. Devices such as detonators and boosters are needed to initiate detonation. Whenan explosive isdetonated, the shock wave create micro fractures and initiate the breaking process in the body of the rock. The gas expand the drill hole at high pressure resulting in cracks. The expansion continues until the entire rock is broken into pieces. The charges are usually placed in series of holes and the holes are fired at a predetermined order.

When an explosive is excited, the compact explosive is transformed into glowing gas with massive pressure. In a densely packed hole, the pressure usually exceed one hundred thousand atmosphere (100,000 atm). The high pressure shatters the area adjacent to the drill hole thereby exposing the rock within the area to high stress. The gas pressure further extend the cracks in the rock, thus tearing the rock into multiple fragments. Though rock blasting is a commercially viable venture, it is advised to be careful at the planning stage in order to produce a blast design that will ensure optimum blast result. The design should be made to enhance proper utilization of blasting energy in the rock fragmentation. This involves minimizing cost through less explosive consumption, less explosive energy, less throw of blasted materials and a significant reduction of blast vibration in order to achieve reasonable safety and stability of structures around the blast area (Manmit and Chinmay, 2007).

Typical example of explosives used for blasting include: ammonium nitrate/fuel oil (ANFO), Emulsions, explosive gelatins, explosive powders etc. In seismic exploration, explosives are categorized into low and high explosive. Low explosives are usually mixtures of combustible substances and oxidants that decomposes rapidly and burn slowly while high explosives detonates with explosive velocity ranging from3 to 9km/s (Wikipedia 2010).

Blasting procedure involves filling drilled holes with detonated explosives. Explosive detonation induces pressure in the rocks, thereby creating cracks in their surfaces and the entire rock mass fracture and disintegrate into fragments(Torbica and Lapcevic 2016). A number of earth scientists have conducted research in this area and their findings have been well reported (Kwon et al., 2009; Ouchterlony et al., 2002; Hustrulid and Lu, 2002).

Pradhan (2002), investigated the trend of blasting in Indian Open cast mines and discovered that it has been changing with requirements. According to him, there are new explosives required for delay detonations, blast performance monitoring, cost effective explosive formations etc. He however noted that even with optimum blasting pattern with systematically chosen explosives, more needed to be done for effective blast control and management.Pal and Ghosh (2002) investigated the optimization blasting pattern used at sonepur Bazari opencast project to manage noise and ground vibration associated with blasting in order to increase efficiency. Their results showed that when there is appropriate design of blast parameters, the desired blast result is usually obtained. They suggested an ideal blast design that will ensure a balance between the environment and efficient blast system.Sethi and Dey (2004) investigated the blast design in Indian mines and discovered most of the designs were based on trial and error approach. They noted that by adopting computerized blasting system, the difficulty associated with the previous method can be overcome.Konari *et al.*,(2004) undertook a study on rock blasting and discovered in their findings that blast casting is an advanced system of blasting for overburden removal in open cast mines. Its implementation arises from the continuous increase and demand for coal due to steady need for power supply.Kurmar *et al.,* (2004) attempted to examine the potential of bulk explosive resulting from increase in rock excavation targets. They studied the performance of the explosives in selected mining centers and deduced that with increase in tensile strength of rock, there is a corresponding increase in the powder factor. Adding that when there is increase in blastability index, the density and p-wave velocity increases.

II. OVERVIEW OF BLASTING PROCEDURE, DESIGN, TYPES AND FORMS OF BLASTING

2.1 Blasting procedure

Blasting procedure plan is usually done prior to blasting before inserting explosives. The holes are drilled in three different patterns using the drill rig. The patterns are the parallel cuts, V cuts and the fan cuts respectively. The parallel cuts are usually associated with hard rock formations while the V cuts are used in all kinds ofgeologic formations. Fan cut is suitable in fractured rocks but not easily found.The harder the rock, the more the explosive. The blasting procedure include the points discussed below.

Loading

Once the holes are drilled to the desired depth (usually 2.4-3.6m), they are then loaded with charges and detonators while a primer is lowered into the bottom of the holes. Explosives are pumped into the holes around the detonator and primer. The end of the holes are filled with stemming which act as a plug by forcing the energy of the explosive to spread to the surrounding rock. Once the entire holes are charged, there are wired to explode in a particular pre-determined order (one after the other at a certain interval of time).

Ignition and detonation of charge

The ignition system include the following elements: electric detonators (used to trigger the explosive), non-electric detonators connected to the ignition point and the detonating cord. The cords are used to effectively chain multiple explosive charges together.The volume of brakeage that may occur with a known quantity of explosive can be calculated using Kuznetsov's equation. This equation was developed by Kuznetsov (1973) and modified by Cunningham (1988) for ammonium fuel oil (ANFO) based explosives as expressed in the equation.

$$X_m = AK^{-0.8}Q_E^{\ 0.167}\left(115/S_{ANFO}\right)^{0.633}$$

Where:
Xm = mean fragment size (cm)

A = blastability
K= specific charge (Kg of explosives/m^3 of rock)
Q = mass of explosive (kg)
S_{ANFO} = relative weight of explosive to ANFO
The blastability index according to Lilly (1986) is calculated from the equation below.
A = 0.06(RMD+JF+RDI+HF)
Where:
RMD = rock mass description
JF= joint factor
RDI = rock density index
HF = hardness factor
The above factors are obtained from in situ geologic data such as: rock specific gravity, young modulus, unconfined compressive strength etc.

Dislodging and ventilating

After blasting the rock debris need to be evacuated. In addition, the blast causes dust fumes mixed with combustion gasses to spread over the tunnel. Before work can resume in the tunnel, the chaotic dust situation must be dealt with. All these can be achieved by ducting and dislodging.

2.2 Blast design

Ground vibration is a product of rock blasting occasioned by poor blast design and inappropriate blastparameters used. These parameters include the distance between the blast and the observation point, characteristics property of the rock mass and geology of the area (Arpaz and Elevi, 2010; Liang *et al.*, 2011). A good blast design is a function of the type of explosive and quantity of energy, diameter of the blast hole, orientation of the ore body and ore properties and rock type. A successful blast must satisfy the following conditions: the explosive in each blast hole must be completely detonated, the detonator position, charge length, initiation plan, quantity of detonators in each drilled hole, delay time must be appropriately determined. Some of the blast parameters are summarized in table 1 (Wyllie and Mah, 2005).

Table 1: Quarry blast design parameters (Wyllie and Mah 2005)

S/No.	Parameters	Symbol	Value
1	Blasthole diameter (inch)	D	1.25
2	Blasthole diameter (mm)	D	39
3	Blasthole length	H	6.41
4	Burden (m)	B	1.12
5	Blasthole spacing (m)	E	1.40
6	Stemming length (m)	H_o(s)	1.12
7	Length of ANFO charge (m)	L	5.28
8	Weight of ANFO charge (Kg)	Qŵ	5.42
9	Specific charge (Kg/m^3)	Q	0.57
10	Specific drilling (m/m^3)	I	0.68
11	Mean fragment size (cm)	X_{fs}	15.00
12	Coefficient of uniformity	ŋ	1.80
13	Total drilling blasting cost (TL/m^3)	M_t	2.54

2.3 Types of blasting

Primary blasting

Primary blasting is the first stage of rock reduction in any blasting operation. It is used to break the rock mass into sizes that may be required by the end user. If the rock fragments are not suitable enough to serve the desired purpose, the pieces can be further subjected to secondary blasting where more treatment is given to the rock.

Secondary blasting

Secondary blasting is applied if the first blast (primary) is not effective. It is necessary to further crush the rock into tiny fragments that can conveniently be handled by the excavator. Secondary blasting could either be plaster (mud-cap) blasting, or pop shooting blasting. Plaster blasting involve firing an explosive charge placed on the rock surface and carefully covered it with clay (mud cap) while in pop-shooting, a hole is drilled into the rock mass before a charge can be fired into it.

2.4Forms of blasting and blast mechanism
Open mine blasting and Quarrying

Open pit mining is a simple way of extracting minerals from an open pit. It is a shallow mining operation that does not involve tunneling into the earth. Minerals are usually tapped using open pit (open cast) mining if the ore deposits are found close to the surface (Figure 1). Both mining and quarrying are extractive processes that involve excavating the subsurface with the view of taking out the earth's minerals. Okeke (2017), defined mining as a method of extracting economic minerals from the earth interior for the advantage of mankind. Conversely, a quarry is an open pit mine used for the extraction of minerals.

Figure 1: Open mine blast (Wikipedia 2016)

Blasting as an essential and integral part of mining cycle is illustrated in a flow diagram shown below(figure 2).

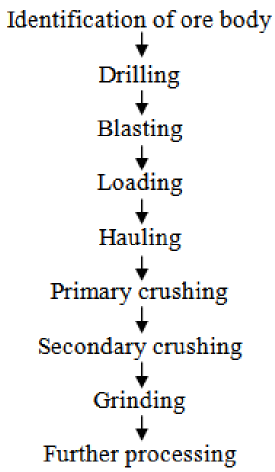


Figure 2: mining cycle flow diagram

The factors which affect the degree of ground vibration during surface mining include: maximum charge/delay, total charge blasted, rock properties, blast duration, blast pattern/ initiation sequence, direction of blast with respect to rock body and the radius and depth of the hole.

Typical examples of active mines and quarries in Nigeria where rock blasting operationis carried out is shown in table 2 below:

Table 2: Some active Mines and Quarries in Nigeria (Ukpong, 2012; Okeke, 1997 & 2017).

S/No.	Mines/Quarries	Location
1	Coal Mine	Enugu (South-East, Nigeria)
2	Coal Mine	Okaba (North Central, Nigeria)
3	Iron Ore Mine	Itakpe (North Central, Nigeria)
4	Lead-zinc	Abakiliki (South-East, Nigeria)
5	Andesite Quarry	Uturu-Okigwe (South-East, Nigeria)

6	Diorite Quarry	Lakpaukwu-Okigwe (South-East, Nigeria)
7	Diorite Quarry	Ishiagu (South-East, Nigeria)
8	Dolerite Quarry	Afikpo (South-East, Nigeria)
9	Granite Quarry	Akamkpa (Oban massif, South-South, Nigeria)
10	Limestone Quarry	Nkalagu (South-East, Nigeria)

Underground blasting and tunneling

Underground blasting is a basic method of rock excavation in underground mining. The history of tunneling is traced back to the Babylonian ancient times where it was used as a source of raw material for the production of metal bearing tools. For years, tunneling in rocks was characterized by building fire against the rock surface which causes expansion and spalling of the rock(Wahlstrom, 1973).Tunneling is a hazardous project in engineering project work hence, requires extensive planning. Mahtab and Grasso (1992), created a flowchart showing the general sequence of activities undertaken in tunnel design and construction. Site characterization, rock mass characterization and tunnel geometry were some of the factors identified (figure 3).

Figure 3: underground blasting (Wikipedia 2016)

Seismic blasting

Seismic exploration is concerned with the application of artificially generated elastic waves to locate mineral deposits such as hydrocarbons, ores, water, geothermal reservoirs etc. aside mineral exploration, archaeological sites and geologic information for engineering site investigation can be obtained from seismic blasting. Seismic source according to Sheriff (1991), is a device which gives out energy into the earth in form of seismic waves.There are basically two categories of seismic sources: land seismic and marine seismic sources respectively.During land seismic blasting, the energy source (dynamite)is detonated, resulting in the generation of seismic waves which travel through various geologic interfaces and return to the surface to be detected by geophones (Figure 4). This wave induce vibration in the earth while propagating through it (Dick *et al.*, 1987). Ground vibration due to seismic exploration is determined using seismograph which record the vibration in seismogram (Stagg and Engler 1980). During seismic data acquisition, the explosives are used as follows:after geophysical survey to delineate the zone of interest, a hole is drilled to a depth of about 6-20m. The charge is placed in the hole and then detonated with electrically ignited blasting cap. In marine seismic, the seismic source is an array of air guns towed by a marine vessel (Figure 5). The gun send high pressure waves into the water causing vibration in the water body. The wave travel to the sea bed and return to the surface to be detected by hydrophone in the same manner as land seismic. However, the detonators and explosives are usually stored and transported separately to reduce the risk of accidental explosion.

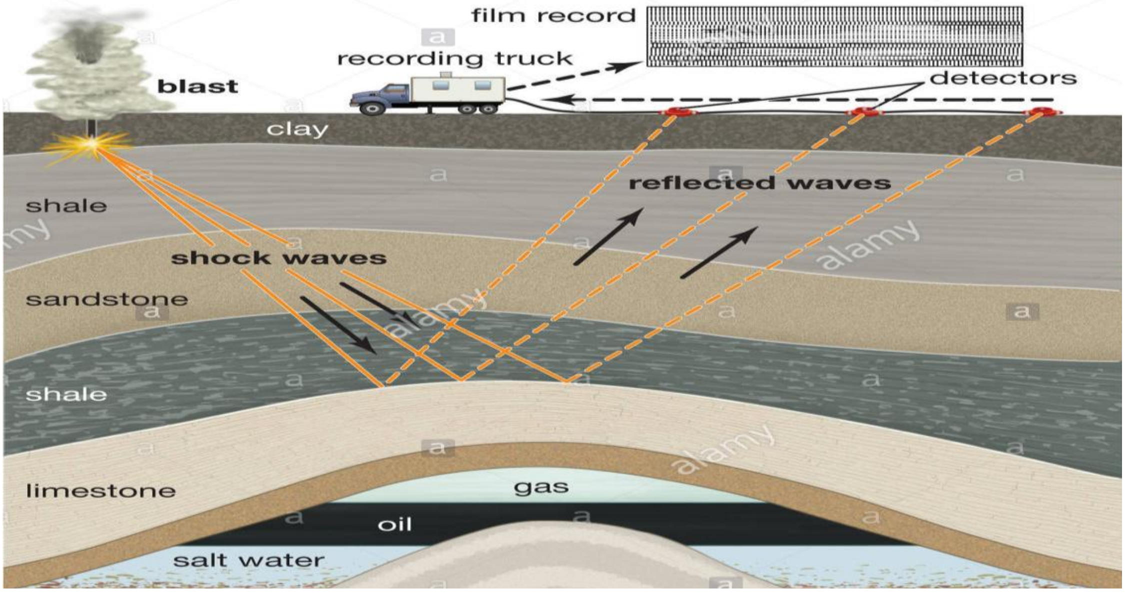


Figure 4: Land seismic blasting (2012 Encyclopaedia Britannica, Inc.)

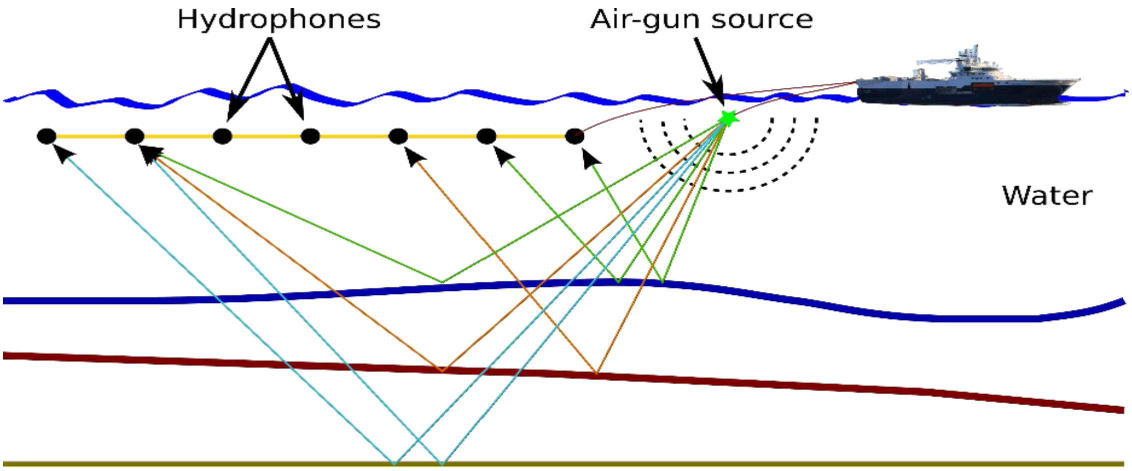


Figure 5: Marine seismic blasting (2012 Encyclopaedia Britannica, Inc.)

Ground Vibration duetoSeismic waves propagation.

Encyclopedic Dictionary of Exploration Geophysics defines seismic wave as an elastic disturbance which is propagated from point to point through a medium. This elastic energy is caused by explosion when a rock mass in the subsurface suddenly split into fragments either through natural means (earthquake) or when artificially induced (blasting). There are basically two prominent types of seismic waves: body wave (p –wave and s-wave) and surface wave (Love wave, Rayleigh wave, ground roll etc.) (Sheriff, 1983). Other types of wave include: air wave also known as shock wave, standing wave etc. The seismic waves are responsible for the variation of elastic deformation in rocks.

Body waves:

The body waves are divided into two: the P- wave also known as primary wave travel faster than S-wave and are responsible for changes in volume of a material. The second type is the S- wave also known as secondary wave. S-waves are responsible for changes in shape of a material. Both P and S wave propagate away from the source with an expanding spherical wavefront. The energy density proportional to $1/_{r^2}$ and the amplitude proportional to $1/_{r}$ (where r = radius of the wavefront) (Figure 6)

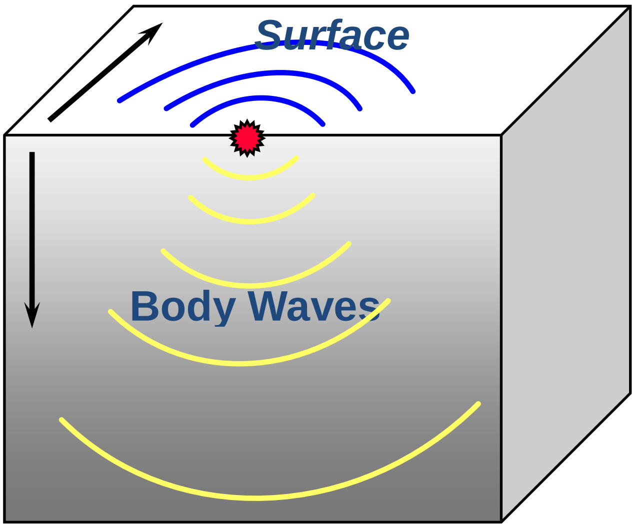
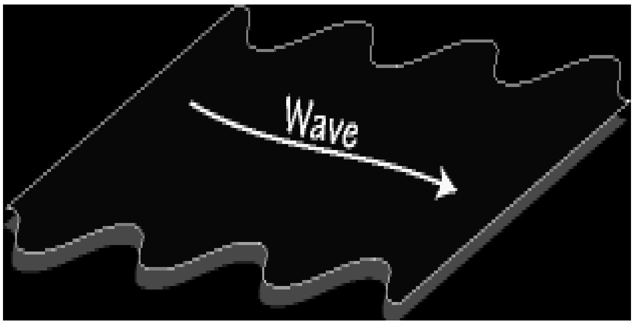


Figure 6: Seismic waves (Saheen *et al.*,2006)

Surface waves

This category of waves transmit energy along the surface of rock materials. Example is love and rayleigh wave. During wave propagation, love wave move from side to side in a snake-like manner. The wave vibrate the ground from side to side without vertical movement (Figure 7). Rayleigh wave on the other hand, vibrate the ground in an elliptical pattern (Figure 8). It moves in a rolling pattern like an ocean wave. In both cases, the energy density is proportional to $1/r$ (r = wavefront radius). The overall movement of body and surface waves through the subsurface is illustrated in figure 9(Saheen *et al.*,2006).



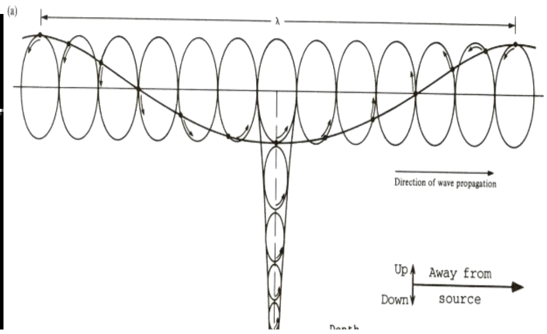


Figure 7: Love wave(Saheen *et al.*,2006)Figure 8: Rayleigh (Saheen *et al.*,2006)

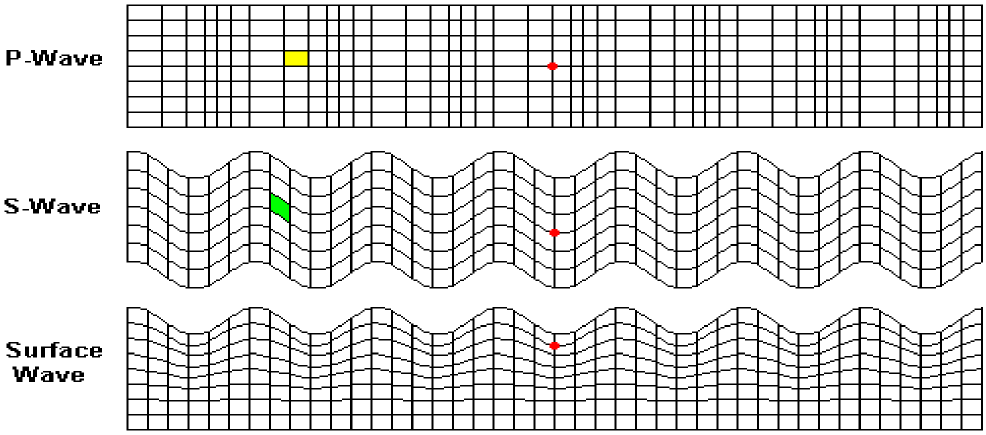


Figure 9: Vibration of seismic wave through the earth (Saheen *et al.*,2006)

III. EFFECTS AND CONTROL OF GROUND VIBRATION ASSOCIATED WITH BLASTING

3.1 Effects

The effects of ground vibration due to rock blasting can be classified into structural and non-structural component. The structural effects include: cracking of foundations and walls of buildings, braking of windows/doors, tearing of roofing sheets while the non-structural include: noise and dust fumes which constitute environmental pollution. Tiwari *et al.,* (2000) reported that steady exposure to a certain level of noise can cause physiological impairment.A study of rock blasting from quarry operation carried out in some communities in the Lower Manyakrobo District in Eastern Ghana revealed serious concerns about the impacts of mining activities in the area. The effects according to this research was more on buildings, farmlands and hydrogeology of the area.Many buildings in the area were reported to have developed varying degrees of cracks with some almost collapsing (Vincent *et al.,* 2012). On a general note, the effects of ground vibration associated with rock blasting are quite massive because most blasting companies don't complywith environmental laws.

3.2 Ways of Controlling ground vibration

In order to control ground vibration due to rock blasting, the following procedure should be put in place. Reducing the weight of explosive per delay, eliminating buffer shooting, changing the direction of blast initiation, reducing the total time of blast, blasting according to wind direction and using non-electric shock-tube instead of detonating cord.Similarly, the devastating effects associated with blasting due to mining, quarrying, tunnelling can be minimized by conscious implementation of the following points:proper blast design and appropriate use of blast parameters,Strict adherence to environmental laws,pre-inspection of drilled depths before loading of explosives, proper loading and firing of explosives etc. In seismic blasting, active, passive and hybrid control devices can be used to control the passage of seismic waves.

IV. CASE HISTORY; EFFECTS AND CONTROL OF GROUND VIBRATION DUE TO BLASTING OPERATION IN SOME QUARIES IN EKITI STATE, NIGERIA

Adetiloye and Nemuwa (2017) undertook a survey in order to evaluate the effects of ground vibration due to rock blasting in parts of Ekiti State. The data was acquired in three different and quarry locations. Shock wave, chaotic dust, noise, blown off rooftops, crack walls, shattered windows and land slide were the seven different effects considered for the study. The result analysis showed that in location one, shock wave, dust fumes, crack walls and broken windows were the major effects. In the second location, the recorded effects were shock wave, dust fumes, noise, damaged rooftops, crack walls and landslide while the third location had shock wave, dust fumes, noise and crack walls as the main effects.

Putting in place appropriate control measures such as: using non-electric shock tube for blast initiation instead of detonating cord, reducing the weight of explosive and blasting according to the wind direction will minimize these effects.

V. CONCLUSION

Rock blasting though environmentally degrading, is found to be substantially lucrative when carried out in a commercial scale. However, in undertaking this economic activity, it is important to carry out the operation in a manner that would not induce excessive near surface vibration. It iscritical to carefully design a blasting plan that would be friendly to both the blaster and the environment. As already established, the effects of ground vibration due to rock blasting are massive though underreported in some places.Both the blast parameters, type of explosives and detonating procedure as integral parts of successful blast should be keenly examined. A proper control system aimed at reducing the effects of ground vibration should be activated. It is also recommended that government should enforce environment laws and all those operating blasting firms should be made to comply so as to reduce the level of ground vibration.Finally, during geophysical exploration, seismic sources with large energy and high impact level should not be used in residential areas. Moreover, passive and hybrid devices should be used to control the passage of seismic waves through the ground.

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